Geology and Mineral Deposits of the Area South of Telluride Colorado

By JOHN S. VHAY

CONTRIBUTIONS TO ECONOMIC GEOLOGY

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CONTENTS

ILLUSTRATIONS

[All plates are in plate volume]

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By John S. Vhay

ABSTRACT

An area between Telluride and Ophir that has had considerable mineral production has been studied as part of the resurvey of the mineralized region of the San Juan Mountains.

The youthful topography, with a total relief of almost 5,000 feet between the peaks and the bottoms of the canyons, is the result of erosion that followed several periods of uplift of the San Juan peneplain, with repeated glaciations that formed a fretted upland. Melting of the frozen matrix of the extensive talus is an important factor in the formation of several types of rock streams. Considerable soil covers the old upland surfaces and the floors of the glacial basins.

Gently dipping sedimentary rocks of Permian, Triassic, Jurassic, and Cretaceous age are overlain with slight angular unconformity by nearly flat-lying Tertiary sedimentary and volcanic rocks. These layered rocks have been invaded by dikes, plugs, and stocks of rocks of intermediate composition.

The older sedimentary rocks are correlated with the upper part of the Cutler formation, the Dolores formation, the Entrada sandstone, the Wanakah and Morrison formations, the Dakota sandstone and part of the Mancos shale. The Telluride formation is at the base of the Tertiary section, and the remainder of the section is volcanic in origin. As this area is on the west flank of the great San Juan volcanic pile, west of the Silverton caldera, the section contains only a few of the volcanic units recognized farther east; the San Juan breccia, Eureka rhyolite, Burns latite, and Potosi volcanic series have been mapped. The San Juan breccia is the thickest unit of the section and consists of a few hundred feet of waterlaid tuff overlain by nearly 2,000 feet of volcanic breccia, much of which may have come into this area as volcanic mudflows. The Eureka rhyolite is represented by latite flows overlain by breccia. The Burns latite locally is a basal volcanic conglomerate, which is overlain by breccias and flows; in the eastern part of the area a few thin flows possibly representing the pyroxene andesite have been mapped with the Burns latite. The Potosi volcanic series consists of an alternation of quartz latite "flows," and rhyolite "flows," that may actually be welded tuff beds.

The intrusive rocks consist of: two stocks, one a composite intrusion of diorite and monzonite, the other composed only of diorite; several small plugs of diorite or monzonite; a number of andesite and latite dikes, concentrated especially in the southwestern part of the area; several small intrusive masses

and plugs of quartz-feldspar porphyry in the southeastern part of th Breccia pipes are associated with some of the porphyry plugs.

The structures in the area were produced by two main periods astrophism. Tilting to the northwest and some faulting took place i Tertiary time, probably during the Laramide revolution. In late Tertiar a slight tilting to the east and much fracturing took place; some of this fr ing is associated with the formation of the Silverton caldera, both as fracture zones and as fractures concentric to the caldera. Other fractur related to the intrusive bodies in the southwestern part of the area. Be the caldera and the general area of quartz-feldspar porphyry intrusions i southeastern part of the area is a zone of horsts and grabens. A co graben in the western part of the area and a few major faults elsewhere a obviously related to either center of structural influence.

The first claims were staked in this region about 1875, and the early de ment of small mines in the near-surface oxidized ores was rapid. The adve a railroad in 1890 further spurred development of the mines. Although o few large mines were developed, there were many small operations.

In general gold has been produced from westward-trending veins in the r half of the area, and silver and base metals from veins of variable trends i south half of the area; notable exceptions are the Gold King and Suffolk m in the southwest part of the area, which yielded much gold. Gold has produced from quartz veins, which generally contain pyrite and in plac little galena. The silver and base-metal veins contain galena, chalcopyrite, te hedrite, sphalerite, and pyrite in a gangue consisting of quartz, ankerite, ba and, in places, fluorite, rhodochrosite, or gypsum. Sparse molybdenite hubnerite are found at a few places.

The ore deposits are fracture fillings; most occur at the intersections of w defined fracture zones with massive, moderately resistant rocks. The most portant hosts for ore are the San Juan breccia and the Cutler and Tellu formations; less important hosts, because they are thinner, are the breccias the Eureka rhyolite and of the Burns latite.

The relative amount of cover appears to have had little influence on the f mation of ore bodies. Rich ore has been mined in Bear Creek and the valley Howard Fork in pre-Tertiary rocks below an altitude of 10,000 feet and as hi as 12,400 feet in the volcanic breccias around Gold King Basin and elsewhe The Potosi volcanic series is an exception in that it fractured so thorough probably because of a lesser load, that ore solutions entering the rock were dilut and few ore deposits formed.

INTRODUCTION

This report describes the geology and mineral deposits of parts the Upper San Miguel and the Iron Springs mining districts, Sa Miguel County, Colo., the area that lies between the San Miguel Rive on the north and the Howard Fork of the San Miguel River on th south, and between the divide on the east side of the San Migue drainage on the east and the area covered by the Silver Moun tain landside (fig. 24). This area is called the South Tellurid area in this report, and includes about 24 square miles that wa mapped in detail. Most of the accessible underground workings o

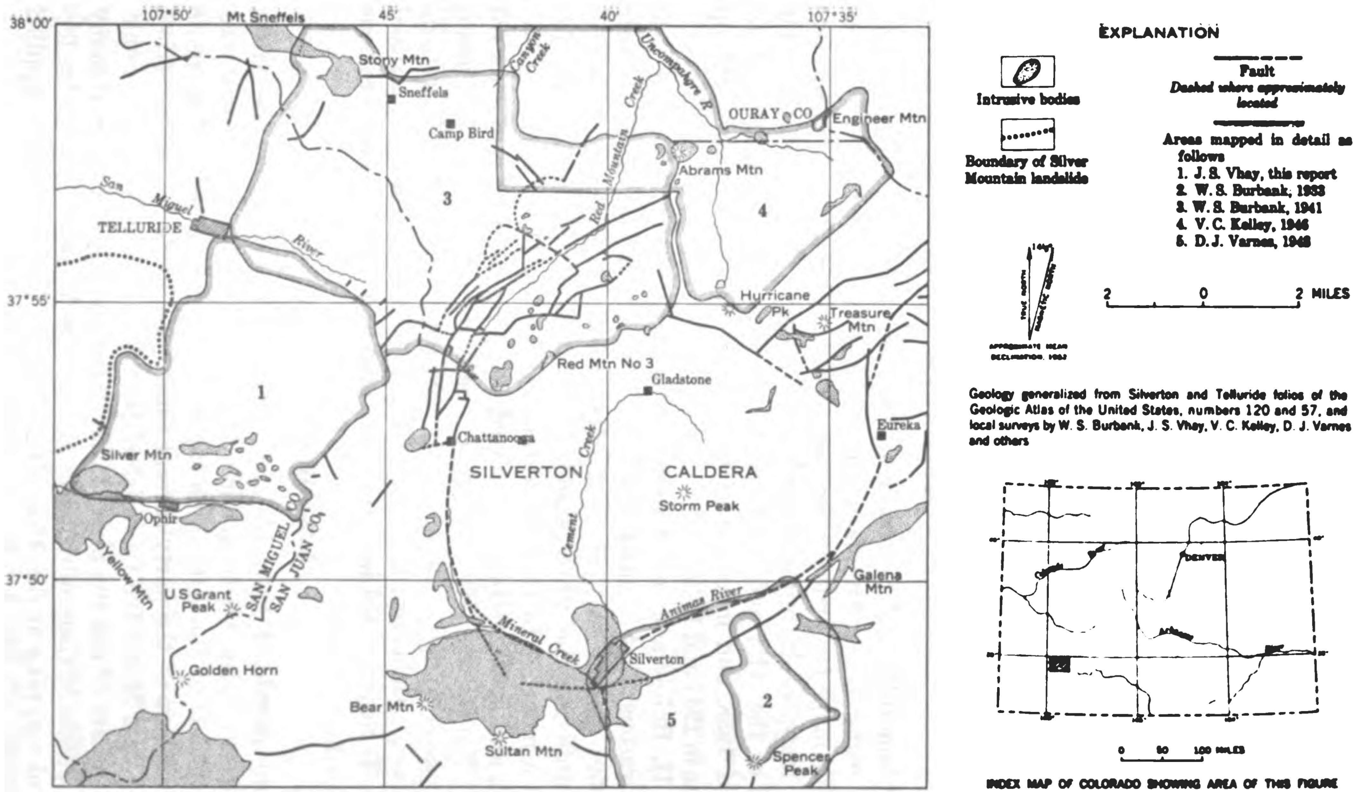

FIGURE 24.—Index map of Silverton caldera and vicinity, showing areas covered by reports by W. S. Burbank, V. C. Kelley, D. J. Varnes, and this report.

the mines were also mapped and studied. The drainage basins Bridal Veil and Bear Creeks, as well as the slopes on the north a northeast sides of Howard Fork, and the headwater areas of Turk and Prospect Creeks are in the area. Altitudes range from abo 8,700 feet on the San Miguel River at the northwest corner of t map to 13,661 feet on Lookout Peak, at the southeast edge of the ma The whole region lies within the Montezuma National Forest.

The work on which this report and map are based is part of larger project by the U.S. Geological Survey in cooperation with th Colorado State Geological Survey Board and the Colorado Meta Mining Fund Board to restudy the geology and mineral deposits o the whole San Juan Mountains area.

FIELDWORK

A plane table and telescopic alidade were utilized in mapping th area, using the triangulation points shown on preliminary topographic maps for primary control. The smaller mines and prospects were mapped during the surface mapping. The accessible older parts of the Alta and St. Louis mines were mapped mostly in the fall of 1938, and mapping of the newer workings was brought up to date in 1941 and 1942.

E. H. Bailey assisted the author during the 1938, 1939, and 1940 field seasons; S. A. Feitler and L. A. Warner for part of the summer in 1939; and in 1941, H. P. Darley and G. R. Prichard served as assistants for the whole summer and Vincent Suarez-Horton for about a month. In 1942 the author assisted by D. J. Varnes, J. W. Odell, and J. W. Gabelman, started mapping the valley of Howard Fork; Varnes was left in charge of the party when the author found it necessary to devote his efforts to wartime investigation of strategic minerals. Fieldwork was resumed in 1947 when the author, assisted by L. T. Silver, filled in gaps in the map and checked some previous mapping.

ACKNOWLEDGMENTS

Many people of Telluride and vicinity were helpful to the party, and it is a pleasure to acknowledge our debt for their assistance. The officials of the Alta mine supplied living quarters and maps to the members of the party several times. Telluride Mines Inc. (then called Veta Mines Inc.) furnished quarters at their Blue Lake bunkhouse a part of one summer. Isaac Partenan supplied maps of many mines, some of them now inaccessible. Abe Wood assisted in underground mapping at the Alta mine. Mayor Noyes of Ophir supplied information on the local mines. Buck Lill shared his living quarters with the party in Jackass Basin in 1940 and 1941, as did Messrs.

Chenoweth and Loomis in 1947 when the higher part of the northeast end of the valley of Howard Fork was being mapped. Several other prospectors were helpful to the party at various times.

Within the Geological Survey, the author credits W. S. Burbank for general supervision of the project and for field conferences, D. J. Varnes for office compilation work on the map and for preparing the information on early work in the area (p. 296), and E. P. Kaiser for microscopic study of the intrusive rocks.

GEOGRAPHY

CLIMATE AND VEGETATION

The San Juan Mountains are well watered, although the San Miguel Plateau, an eastern part of the great Colorado Plateau immediately to the west, is semiarid. Precipitation in the mountains is as much as 40 inches per year (Cross and Larsen, 1935, p. 10). Deep snow accumulates in the higher regions, and, because of the steep treeless slopes, snowslides are frequent and are serious handicaps to mining operations throughout the whole area. The deep snow melts slowly and much is still present at late as early July. On the north-facing steep slopes, and especially in the narrow, steep chutes cutting them, some snow may remain throughout the year. The months of May, June, September, and October are fairly dry, but during July and August thunderstorms occur almost daily.

The daily temperature has a wide range, and the nights are always cool. According to Cross and Larsen (1935, p. 10),

> The summer temperatures are moderate, the average for July and August being a little over 60°. Temperatures as high as 100° have been recorded, but the altitude is so great and the air so dry that it is comfortable in the shade even on the hottest day * * *. The average temperature in January is from 13° to 20°, but temperatures as low as —34° have been recorded * * *. Frosts are not uncommon in June and September, and they have been recorded for every month of the year.

The types of vegetation in the area have a close relation to the altitude. The abundant moisture supports a heavy forest cover, especially on the north- and northwest-facing slopes. Spruce, intermixed with some pine and fir, is most common. Aspen grows in groves along the water courses, and, together with a thick cover of brush, has overgrown large areas where the coniferous trees have been removed by either forest fires, snowslides, or the intense logging which has been done in the area, especially near the mines. Near timberline the spruces become stunted, twisted, and sparse.

Timberline generally lies between 11,500 and 12,000 (Cross and Purington, 1899, p. 1), approaching the higher altitude only on the north-facing slopes and falling below the lower altitude on drier south-facing slopes.

The north side of the valley of Howard Fork has relatively 1 conifers, except for a zone between 11,000 and 11,600 feet, wh there are fairly dense growths of conifers on the small ridges betw the gulches. The rest of the north side of the valley is cove with dense aspen groves and brush thickets up to an altitude about 11,300 feet; grass and wild flowers grow abundantly betwe the thickets.

Stunted willows grow along the water courses for a considera distance above timberline. The rest of the country, except for the cli and talus slopes, is covered by short grasses and alpine-type flower in places they grow in great profusion, and the variously colored I dian paintbrush and other wild flowers form beautiful carpets of br liant color when in bloom. The alpine flowers become smaller ar smaller at higher altitudes, but a few dwarfed plants are on even tl highest peaks.

ACCESSIBILITY

The region is reached by State Highway 145, from Dolores throug Rico, Ophir Loop, and Placerville to Naturita; State Highway 6 connects Placerville with U.S. Highway 550 at Ridgway. State High way 108 goes from Highway 145 past Telluride to Pandora, and High way 134 from Ophir Loop up the Howard Fork past Ophir, over Ophi Pass and connects with Highway 550 north of Silverton. There ar less-traveled roads from Pandora to the top of Bridal Veil Falls, up Bear Creek as far as the Maryland mill, and into Palmyra and Gold King Basins.

Because of much mining activity in the past, there are fairly good trails up the canyon of Bridal Veil Creek and into the basins tributary to it and other trails wind up through La Junta Basin and along Bear Creek to its east fork. Trails follow the crest of Gold Hill and traverse Prospect Basin. There are also, of course, trails to all the mines or prospects of any size throughout the area; these trails are still generally passable, except in areas where talus movement has destroyed them.

Aerial trams were used a great deal by mining companies because the steep slopes, talus, and winter snowslides made road building and maintenance difficult. The only tram in operation as recently as 1947 goes from the top of Bridal Veil Falls to a point on the road to the falls at an altitude of about 9,450 feet; the Palmyra-St. Louis tram to the Alta mill, and one from that mill to Ophir Loop were in operation as late as World War II. The cables of the tramway from the Carbonero mine to the mill were still up in 1947.

DEVELOPMENT OF WATERPOWER

This area has the distinction of being one of the first places where electrical power was transported fairly long distances. As Chester Purington wrote in 1897 (Cross and Purington, 1899, p. 15) under the heading "Recent Progress."

> The electric transmission of power generated by water has attained important development. Stamp mills are operated by electric power at distances of more than 10 miles, in a straight line, from the generating station, near Ophir Loop, and at elevations of 2,000 or 3,000 feet above the source of the power.

A powerplant that uses water from both Howard Fork and Lake Fork of the San Miguel River is still in operation below Ophir Loop.

The Telluride Mines, Inc., has an extensive system of dams and pipelines for water conservation and use in Bridal Veil Basin. Power generators are located at the top of Bridal Veil Falls and at the mill at Pandora. Dams to conserve water for use during low-water periods have been built at Lewis Lake, Mud Lake, and Silver Lake. A tunnel, located on the next flat below the rock lip of Blue Lake, taps the lake at considerable depth and serves as the starting point for the pipeline to the power plant at the head of Bridal Veil Falls. Blue Lake itself is further supplied with water by pipelines from Lewis Lake and from the west branch of Bridal Veil Basin (locally called Double Eagle Basin). The vertical drop from the surface of Blue Lake to the generator at Bridal Veil Falls is roughly 1,900 feet; from Bridal Veil Falls, where the water from the tailrace of the generator and also from Bridal Veil Creek enters a large pipe, down to the generator at the mill is another drop of 1,200 feet.

Some additional waterpower is available in the district from Bear Creek and smaller streams like Deertrail, La Junta, Prospect, and Turkey Creeks, but, although the fall is great, the water supply is extremely variable, ranging from flood conditions every spring and early summer to very low stages in the fall and winter. Because of these conditions, Telluride Mines, Inc., has made an effort to conserve water in Bridal Veil Basin.

TOPOGRAPHY

The country between the San Miguel River and the Howard Fork of the San Miguel River is extremely rugged. About 17 peaks in this small area stand at altitudes between 13,000 and 13,661 feet (the altitude of Lookout Peak), whereas the altitude of the San Miguel Plateau to the west ranges from 10,000 feet near the mountains to 8,000 feet farther west.

The two main drainage lines are the nearly straight valleys of the Howard Fork and the San Miguel River, which trend westward out of the mountains. From an altitude of 10,517 feet (Beaver La at its east end, the valley of Howard Fork descends to about 9,200 : at its west end at Ophir Loop. Only a number of steep talus-fil gulches cut the north side of the valley, but two larger tributar Swamp Creek and Waterfall Creek, do enter the Howard Fork fr south of the map area.

The valley of the San Miguel River descends from an altitude about 9,000 feet at its head, east of Pandora, to 8,600 feet 6 miles w where the river plunges down to join the South Fork, cutting deep canyon that continues through the San Miguel Plateau. T two large tributaries, Bridal Veil and Bear Creek, flow northwa into the San Miguel River, and Prospect and Turkey Creeks fl northwestward out of the mapped area.

This whole mountainous region has been glaciated into a frett upland. Only a few small patches of probable remnants of the pr glacial topography remain. Among these are the high rounded are south of the Gold King Basin, the upper part of Gold Hill and tl area around Green Cone, the east side of La Junta Peak, the ar southwest of Bridal Peak between altitudes of 13,100 and 13,2(feet, and the hill north of Silver Lake Basin (altitude 12,270 feet These small areas appear to have somewhat more soil cover and hav not been deeply scoured by ice. Some of them may be parts of th San Juan peneplain or of the landscape formed during the Florid erosion cycle, older erosion surfaces now represented only by gentl sloping remnants in the higher mountains (Atwood and Mather, 193 p. 21–29).

In the whole region most of the ridges around the cirques are aretes with cols between them at altitudes between 12,840 and 13,160 feet Most of the high points in the area are typical horns; the more prom inent ones are listed below together with their altitudes (asterisks in dicate triangulation points):

	Altitude (feet)
Lookout Peak*	13, 661
Unnamed peak, north of Lookout Peak	13, 614
Wasatch Mountain*	13, 555
Bridal Peak*	13, 510
Three Needles*	13, 481
La Junta Peak	13, 472
Silver Mountain*	13, 470
Palmyra Peak	13, 319
Ballard Mountain	12, 804

In addition to these peaks, at least seven more horns in the mapped area stand above 13,100 feet.

GEOLOGY

SUMMARY

The bedrock in the area south of Telluride can be classified into three main types—sedimentary rocks, volcanic rocks, and intrusive igneous rocks (pl. 16). Most of the sedimentary rocks are pre-Tertiary (late Paleozoic and Mesozoic) in age: one sedimentary formation and all the igneous rocks are Tertiary in age.

The pre-Tertiary sedimentary rocks comprise the Cutler formation (Permian), the Dolores formation (Triassic), the Entrada sandstone and the Wanakah and Morrison formations (Jurassic), and the Dakota sandstone and Mancos shale (Cretaceous). Most of these formations crop out along the bottom and lower sides of the canyons of Bear Creek and the San Miguel River. Some are also on the lower part of the west side of the Ophir Needles, and in the valley of Howard Fork as far east as Beaver Lake. The rocks are much metamorphosed around an intrusive body that comprises the Ophir Needles.

The Telluride formation is at the base of the Tertiary section, between the pre-Tertiary sedimentary rocks and the Tertiary volcanic rocks. Unless covered by landslide material, the formation crops out in an imposing cliff almost everywhere, except in the eastern part of the valley of Howard Fork where intense hydrothermal alteration has weakened it.

Except for a relatively small area underlain by dikes and stocks, the Tertiary volcanic rocks form the bedrock of the remainder of the mapped area. The San Juan breccia at the base consists in large part of pyroclastic material; the Eureka rhyolite contains some flows but is more than half pyroclastic material; the Burns latite consists mostly of flows, and the Potosi volcanic series is made up mostly of thick "flows," some of which may be welded tuffs.

Most of the intrusive plugs, stocks, and similar intrusive bodies are found only in the valley of Howard Fork or in an area within a relatively short distance north of it. Diorite intrusions occur as two fairly large stocks, 6,000 to 8,000 feet in greatest diameter, and several smaller bodies are in the western half of the valley and in the area to the north. Quartz-feldspar porphyry occurs as one or more poorly exposed but fairly large bodies and small plugs in the valley of Howard Fork east of the diorite masses. Breccia pipes are associated with some of the small plugs.

Many dikes, a few feet to several tens of feet wide, are present in the South Telluride area. They are most abundant in the west half of the valley of Howard Fork, around Gold King, Palmyra, Prospect and Lena Basins, and on the south side of the basin of the East Fork of Bear Creek. A few are scattered throughout the rest of the area.

The dikes are generally composed of dark greenish-gray ande rocks, which show a wide variety of textures and contain a variet minerals as phenocrysts. Contact metamorphism of the enclo rocks consists only of a slight baking, which changes the color usually increases the resistance to erosion slightly. Many dikes v injected along faults, or were the sites of later faults. Most d are hydrothermally altered along their contacts.

Not much is known about the pre-Tertiary structure of the a Around Telluride the pre-Tertiary formations dipped northwest the time the Telluride formation was deposited, for it rests on ero Dolores formation at Bridal Veil Falls and along Bear Creek j north of the Nellie mine, whereas it rests on part of the Morris formation at Telluride. In the valley of Howard Fork, the metam phosed Pony Express(?) limestone member of the Wanakah forn tion not far below the Telluride formation dips northwest, where north of Ophir Loop, farther west, intensely metamorphosed Manc shale underlies the conglomerate. Only two pre-Tertiary faults we recognized although they may be more common. A northeastwar striking fault, exposed in the south wall of the canyon of the Sa Miguel River southwest of the Smuggler Union mill, had two perio of movement—one in pre-Tertiary time and one during the Tertiar

In general it appears as though the volcanic section dips eastwa between 5° and 10°, even allowing for the fact that many of the fo mational contacts in the volcanic section are irregular surfaces, an probably none of the contact surfaces were flat when the overlyin units were deposited.

In Tertiary time the faulting and mineralization in the area ma have been controlled by events that occurred in two distinct and sepa rate centers. Just east of the area (see fig. 24), a large subsided bloc that has been called the Silverton caldera (Burbank, 1933, p. 160; 1940 p. 246) apparently had a strong influence on the structural features in the eastern and northern parts of the mapped area. Forces associated with the intrusive center along the valley of Howard Fork had a strong influence on the structures in the southwestern and southern parts of the area.

The radial faults from the caldera cross the north half of the area, striking a little north of west. The young northeastward-striking faults are concentric to the caldera, and trend more to the south as they approach the valley of Howard Fork. These faults have downward movement on the east side. There are also a few north- and northwestward-trending faults.

The structure and ore deposits in the southwestern part of the area presumably are greatly influenced by the diorite intrusion at

Ophir Needles and by the other diorite stock in Spring Gulch. Here the dikes, faults, and veins are in zones that trend west-northwest, northeast, and north. On the west side of the mapped area there is a graben wherein the Potosi volcanic series is downfaulted between San Juan breccia, but most of this structure is covered by landslide material.

There are many northeastward-trending fracture zones throughout much of the valley of Howard Fork, and a zone of weakness lies between the group of quartz-feldspar porphyry intrusions in the eastern part of the valley and the Silverton caldera. There several grabens and horsts are bounded by eastward- and northwestward-striking faults.

Gold is present along the westward-trending radial faults in the north part of the mapped area and along a few northward-trending zones in the southwest part. Base metals and silver are present in some of the northward-trending fault zones in the eastern part of the mapped area and in zones of several trends all across the south half.

PRE-TERTIARY ROCKS

The pre-Tertiary sedimentary rocks are exposed only in the lower parts of the larger canyons and have a total thickness of about 1,330 feet. The thicknesses given in the following table are approximate, for the pre-Tertiary rocks, being in the lower slopes of the canyons, are, in general, heavily covered by talus, landslide material, soil, and vegetation. The age relations shown on this table are those given by Burbank (1941).

CUTLER FORMATION

The upper part of the Cutler formation, of Permian age, is exposed on the south side of the canyon of the San Miguel River and for about 2.3 miles up Bear Creek. It consists of more than 500 feet of alternating beds of conglomerate, sandy conglomerate, coarse arkosic sandstone, sandstone, thin-bedded sandy shale, shale, and mudstone. The sandstone beds contain some thin micaceous shale partings, and much of the sandy conglomerate and arkosic sandstone is crossbedded and contains lenses of conglomerate. The beds are maroon, reddish gray, and dull red. The sandstone is locally mottled light gray and red, but the mottling is not everywhere parallel to the bedding. The more shaly beds are usually dull red. Along lower Bear Creek a cliff-forming conglomerate bed, 10 feet thick and about 320 feet below the top of the formation, seems to be fairly persistent and was used as a key bed. On the whole, however, the individual units of this formation are not very persistent; most of the conglomerate appears to be in large lenses. The formation in general is fairly resistant and forms many outcrops.

Pre-Tertiary sedimentary formations

Age		Formations	Thickness (feet)	Description
Mesozoic	Upper Cretaceous	Mancos shale	380+	Thinly bedded black and gray shale, some sand calcareous shale, calcareous nodules, few beds fine sandstone.
		Dakota formation	193	Upper 111 ft gray shale, siltstone and some sandsto Lower 82 ft medium- to fine-grained yellow sandsto
	Upper Jurassic	Morrison formation: Brushy Basin member.	278+	Mostly shale, in places calcareous, and minor amo of sandstone.
		Morrison formation: Salt Wash member.	(?)	Only few feet of irregularly bedded sandstone expo in this area.
		Wanakah formation: Undivided upper section.	110	Top 20 ft, well-bedded sandstone, possible equival to Junction Creek sandstone. Middle 60 ft, calcareous shale and weak sandsto beds. Bottom 30 ft, medium-grained yellow sandsto more massive lower half; topped by "carneli sandstone" (18 in.), Bilk Creek sandstone memb
		Wanakah formation: Pony Express limestone member.	18–28	Dark-gray finely laminated limestone overlain limestone breccia and knobby, massive limestone
		Entrada sandstone	32–40	Yellow to buff, medium- to coarse-grained quar sandstone; in part crossbedded.
	Triassic	Dolores formation	300–320	Top 50 ft, yellowish-gray sandy mudstone, ca careous sandstone and limestone conglomera (Wingate equivalent?). Mostly thick-bedded red mudstone, in part calcar ous or sandy; many thin beds of micaceous sand stone, sandy shale and red shaly limestone. Bottom 5–10 ft, conglomerate with limestone pebble grading upwards into white sandstone.
Paleozoic	Permian	Cutler formation (upper part).	500+	Interbedded pinkish-gray and maroon-gray mottle coarse arkosic sandstone, conglomeratic sandston and conglomerate; some thin beds of dark-re micaceous shale and shaly sandstone; many lense of conglomerate and much crossbedding in th coarse sandstone.

DOLORES FORMATION

The Dolores formation of Triassic age (Larsen and Cross, 1956, p. 48) is exposed along the canyons of the San Miguel River and lower Bear Creek, above the outcrops of the Cutler formation. It is also probably present along Howard Fork, but it was not definitely recognized there because of the color change due to metamorphism, and because of poor exposures; it probably comprises the lower part of the area mapped at metamorphosed Mesozoic rocks.

The base of the Dolores formation commonly consists of a white to light-gray conglomerate layer, 10 feet thick. This bed contains some limestone pebbles that serve to differentiate it from the conglomerate in the Cutler formation. This conglomerate layer is less than 10 feet thick in many places and may be missing locally; where it is missing, its place is taken by a white sandstone bed a few feet thick. More than half of the main part of the Dolores formation characteristically consists of bright-red thick-bedded mudstone with some interlayered thin-bedded shale and sandy shale. Distributed throughout the mudstone, and next in abundance to it, are red thin-bedded micaceous, calcareous, or shaly siltstone and fine-grained sandstone beds. Limestone conglomerate is fairly common and thin beds of buff or pink limestone are sparse throughout the section. The bright-red color, the large amount of mudstone, and the highly calcareous nature of much of the rock appear to be characteristic of the middle part of the formation.

The top of the formation is marked by about 40 feet of buff or yellow calcareous beds that appear closely related lithologically to the Dolores, although more detailed mapping of the Mesozoic rocks might show that they could be treated as a separate formation, possibly an equivalent to the Wingate sandstone. These beds consist, from the bottom up, of limestone conglomerate, calcareous sandstone, calcareous sandy mudstone containing limestone pellets, and a calcareous sandstone containing greenish-gray limestone pellets. In places this part of the formation may have been mapped with the overlying Entrada sandstone where it forms the bottom part of cliffs of Entrada sandstone.

The Dolores formation probably is separated from the overlying Entrada sandstone by a disconformity. This is indicated by a few inches of thinly bedded light greenish-gray shale at the top of the Dolores, which appears to the author to represent a slightly reworked soil zone lying on the top of the Dolores. The total thickness of the Dolores formation is between 300 and 320 feet.

ENTRADA SANDSTONE

The distribution of the Entrada sandstone is similar to that of the Dolores formation except that it is more restricted. It not present east of a point approximately a thousand feet west of Bridal Veil Falls, and south of about the latitude of the Silver Chief mine along Bear Creek. Typically it forms a low yellow cliff at the top of the Dolores outcrops.

The Entrada is 32 to 40 feet thick where exposed in the area south of Telluride. It consists of yellow medium- to coarse-grained quartz sandstone beds. The thicker beds in places have crossbedding. At the top it has a sharp contact with the Pony Express limestone member of the Wanakah formation.

WANAKAH FORMATION

The Wanakah formation is more limited in occurrence than the older formations. It does not occur east of approximately the longitude of the Smuggler Union mill along the south side of the valley of the San Miguel River, nor south of the latitude of the Canton mine along Bear Creek, except for the Pony Express limestone men at the base, which extends a little farther east and south. (See 16.) At least part of the formation is probably included in metamorphosed Triassic and Jurassic rocks in the southwestern p of the area, but, because of intense metamorphism, it was not definit recognized. Except for the Pony Express member, the format is poorly exposed, and the subdivisions described below were rec nized only in a few gulches a short distance east of Bear Creek the south side of the valley of the San Miguel River.

The formation can be divided into four members: the Pony I press limestone member at the base, the Bilk Creek sandstone me ber, the so-called marl, and, at the top, a sandstone that is possil the equivalent of the Junction Creek sandstone (Eckel, 1949, p. 2 29). The members above the Pony Express are combined into single unit on the map. The total thickness of the formation is abo 135 feet.

The Pony Express limestone member is 25 to 28 feet thick in mo places. The bottom is 9 feet of thinly laminated platy black to dar gray limestone; this is overlain in places by about the same amou of dark-gray limestone breccia formed by the leaching of gypsu from a gypsum-limestone complex (Burbank, 1940, p. 195, 211), an this is in turn overlain by 8 to 10 feet of gray, massive, somewha sandy limestone that weathers with a knobby surface because o patches of recrystallized calcite and gypsum.

The overlying Bilk Creek sandstone member consists of about 3 feet of yellow sandstone in fairly massive beds in the lower half an thinner, somewhat shaly beds in the upper half. It is topped by th so-called carnelian sandstone, which is about 18 inches of resistan sandstone containing red chalcedony grains.

The next member above consists of about 60 feet of calcareous shale, mudstone, thin beds of shaly sandstone, and shaly limestone. Some of the beds contain small pieces of red chalcedony, and some mudstone contains crystals of gypsum. This unit has been called the marl member of the Wanakah.

About 20 feet of fairly massively bedded cliff-forming sandstone lies at the top of the Wanakah formation as mapped in this area. This member may be the equivalent of the Junction Creek sandstone mapped farther south (Eckel, 1949, p. 27).

MORRISON FORMATION

The Morrison formation west of the South Telluride area consists typically of two parts: the lower Salt Wash member, predominately sandstone, and the overlying Brushy Basin member, mostly shale. The Salt Wash member is probably present only on the slopes on each side of the mouth of the canyon of Bear Creek. It crops out in few places and, except for the bottom few feet above the Wanakah formation exposed in steep gulches, was not recognized during the mapping.

The Brushy Basin member is present only on the west side of the Ophir Needles, where the rocks are intensely metamorphosed. At this place there is about 278 feet of hornfels and minor amounts of quartzite, which probably was shale, calcareous shale, shaly sandstone, and a few beds of sandstone before being metamorphosed.

DAKOTA SANDSTONE

The Dakota sandstone also is exposed in the South Telluride area only in the cliffs on the west of the Ophir Needles. Here, about 82 feet of yellow quartzite is overlain by 111 feet of dark-gray hornfels, gray siliceous hornfels, and a few quartzite beds. The top of the formation is assumed to be the highest quartzite bed, which is 7 feet of gray fine-grained quartzite.

MANCOS SHALE

Only the lower part of the Mancos shale is present in this area. About 380 feet of thinly bedded black and dark-gray hornfels is present on the west side of the Ophir Needles between the Dakota sandstone and the overlying Telluride formation. A few doubtful *Gryphea* molds and fairly abundant *Inoceramus* imprints near the top of the exposed section served to identify these rocks as Mancos shale.

TERTIARY SEDIMENTARY AND VOLCANIC ROCKS

To identify and correlate the formations in a complex volcanic area is generally difficult. In the long period of time during which a large volcanic pile like that found in the San Juan Mountains is forming, many different volcanic centers or craters are active either successively or concurrently. Recurrent activity is possible, with the extrusion of different types of lava at different times. Conversely, similar-appearing lavas may come from different craters. Moreover, volcanic formations may be lenticular in cross section and may interfinger with, or overlap, other formations. Thick breccias may form in one place while flows are being piled up elsewhere. Calderas may form in any large volcanic field (Williams, 1941) and may sink repeatedly. As a result of subsidence, a rock unit may be thousands of feet of massive flows within a caldera, but be absent, or consist of only thin flows or breccias, outside the caldera. Moreover, breccias similar in general appearance and composition may be separated by major disconformities, with or without separating flow units. Such breccias should not be grouped as one formation where there are major disconformities intervening flow formations.

It is very difficult, therefore, to correlate volcanic formations acr any considerable distance in an old volcanic pile without actually m ping the units in the area between. Some previous correlations in San Juan region, especially those made during reconnaissance exa inations, may be in error because of the possible relations pointed above. This is probably true of at least part of Burbank's Picayu volcanic group (Burbank, 1941, pl. 1). This unit was correlated fr the southeast side to the northwest side of the Silverton caldera, wit out detailed mapping of intervening areas. Some of the correlatio proposed in this report leave much to be desired, as the author h neither seen all the type areas nor mapped the intervening countr Moreover, he feels that some of the original definitions and descri tions of the units by Cross and Purington (1899) and by Cross, How and Ransome (1905) are not adequate for modern geologic use.

The area described in this report lies on the west flank of the larg compound San Juan volcanic center. In this center, many volcanoe erupted different types of lava over a long period of time. The wes edge of the Silverton caldera, first described by Burbank (1933, p 160), lies about 2 miles east of the east side of the mapped area. Th caldera sank at different times during its long history, and flows tha are as much as several thousand feet thick in the caldera are repre sented in the South Telluride area by flows a few tens or hundreds of feet thick, which came out over the rim. Moreover, much pyroclastic material accumulated in this flank area while flows accumulated in the caldera; also, much erosion took place in the flank area. Certain formations that are fairly thick in the caldera did not reach some parts of the flank areas. Elsewhere, pyroclastic formations of younger age may have been deposited on much older deposits, and it may be difficult to distinguish the two pyroclastic units.

Of the Tertiary formations described by Cross and Larsen (1935) in the San Juan Mountains, equivalents or partial equivalents of the following units are believed to be present in the mapped area: The Telluride conglomerate, the San Juan tuff, some units of the Picayune volcanic group, flows and breccias of the Eureka rhyolite, volcanic conglomerate, breccia, and flows of the Burns latite, a very little of the pyroxene andesite, and part of the Potosi volcanic series. These rocks have been mapped as the following units: Telluride formation; San Juan breccia; the Silverton volcanic series, which consists of Eureka rhyolite (including andesite of the Picayune volcanic group, typical Eureka rhyolite and the overlying breccias) and Burns latite (including underlying volcanic conglomerate, breccias, Burns-type flows, and one pyroxene andesite flow); and the Potosi volcanic series. These formations are shown in the following table:

Tertiary sedimentary and volcanic formations

Age	Series and (or) formation	Members	Thickness (feet)	Character
Upper or middle Tertiary	Potosi volcanic series	Andesite flow	40	Massive dark-gray flow; found only on Lookout Peak.
		Rhyolite flows	175–250	Massive light-gray flows.
		Quartz latite flow and breccia	75–100	Red flows and breccia.
		Rhyolite flows	250–300	Thick flows of glassy banded rhyolite.
		Quartz latite flows	50–100	Gray quartz-latite flow with dark bands or hard balls of similar rock.
		Quartz latite flows	300–350	Pinkish-gray massive flows with brown biotite phenocrysts.
Miocene	Silverton volcanic series: Burns latite	Pyroxene andesite flow and breccia	40	A few lens-shaped flows associated with breccia.
		Latite flows	70–200	Dark-greenish and reddish-gray flows; massive flows in upper part, fissile-weathering flows in lower part of unit; typical Burns latite.
		Latite breccia	0–150	Breccia and tuff, with volcanic conglomerate at base in places.
	Silverton volcanic series: Eureka rhyolite	Breccia and tuff	250–400	Contains many rock types, but very little like underlying flows.
		Latite flows	10–100	Reddish and greenish-gray flows, characterized by numerous flattened vesicles; typical Eureka rhyolite.
		Andesite flows and breccia	0–25	Dark-gray vesicular flow overlain by a little breccia; may be equivalent to part of Picayune volcanic group farther east.
Miocene(?)	San Juan breccia	Breccia and tuff	1,200–2,100	200 ft of well-bedded tuff at base overlain by fairly massive beds of breccia and local lenses of tuff.
		Andesite flow	0–20	Dark-green flow 450 ft above base of formation.
Oligocene(?)	Telluride formation		300–400	Massive conglomerate composed mostly of Precambrian and Paleozoic rocks; bottom few feet characterized by immediately underlying rocks; top 15 ft is a pinkish-gray, coarse arkose.

Much more detailed fieldwork and petrographic studies will be required before definite correlations can be made and the proper geologic sequence be established for this ancient volcanic pile.

TELLURIDE FORMATION

The Telluride formation[1] in the South Telluride area consists mostly of a massive cliff-forming conglomerate. In the canyons of the

[1] Formerly called Telluride conglomerate. The change to formation is suggested because of the variable lithology of this unit from place to place. In the southwestern part of the South Telluride area it has considerable sandstone and farther west the "formation is [at Mount Wilson] a succession of fine conglomerates, grits, sandstones, sandy shales, calcareous shales, sandy limestones, and dark, or even black, shales." (Cross and Purington, 1899, p. 4.)

San Miguel River and Bear Creek it forms a continuous, nearly ve cal cliff except in the northeast corner of the mapped area, where covered by talus from Ingram Basin, and on the east side of the lo part of Bear Creek, where it is buried by two landslide masses. Al the west side of the mapped area the Telluride formation is cove by the Silver Mountain landslide and some of the smaller slides n the mountain front, except for one small area south of the mouth Gold King Basin. It forms a cliff along the northwest side of t Ophir Needles extending southward to a place where it is cut out the Ophir Needles intrusion. Along the north side of the valley Howard Fork it crops out continuously enough to be mapped, thou rarely forming cliffs, from the east edge of the Ophir Needles intr sion as far as Spring Gulch. East of Spring Gulch the Telluri formation, like all the other formations apparently is weakened l hydrothermal alteration and weathers so easily that there are few ou crops; as shown on the map (pl. 16), exposures were found at on three places, the easternmost being just west of Chapman Gulch.

From a distance the massive conglomerate of the Telluride forma tion is light reddish gray or gray. In detail the color is influence mainly by the color of the constituent boulders. These consist of great mixture of relatively resistant rock types—red and gray sand stone, gray limestone, bluish-gray or gray quartzite, gray granite gneiss, and dark-gray schist; the sandy matrix is stained somewha reddish by iron oxide. The rock fragments range in size from a few inches to as much as 2 feet across and are generally well rounded. A light-pink to white coarse arkose 10 to 15 feet thick tops the formation and contrasts sharply with the overlying dark-gray fine-grained tuffs of the San Juan breccia.

The character of the bottom few feet of the formation changes considerably, depending on the formation that directly underlies it. Where it overlies the Dolores formation, the Telluride has the same bright-red color as the Dolores and contains many boulders of red sandstone and mudstone. Over the Entrada sandstone, the Telluride contains boulders of yellow sandstone, generally with a red matrix derived from the nearby Dolores. Over the Pony Express member, it contains limestone fragments; but over the rest of the Wanakah, it is generally a weak impure sandstone that grades upward into the typical conglomerate.

The Telluride formation is generally between 300 and 400 feet thick. South of the San Miguel River it thins eastward from about 400 feet to about 275 feet; at Bridal Veil Falls, the most eastern point where it is exposed, one doubtful measurement of 180 feet was made. At its most southwestern exposure in the South Telluride area, on the northwest side of the Ophir Needles, it is approximately 450 feet thick, and is in general finer grained than elsewhere in the mapped area, with considerable sandstone both at the base and at the top.

These measurements confirm the statements of Cross and Purington (1899) that the formation thickens to the west (approximately 1,000 feet in the Mount Wilson area) and thins to the east of the Telluride quadrangle. Burbank reports (written communication, 1955) that in Canyon Creek, about 5 miles northeast of the Smuggler Union mill, the conglomerate is locally 25 to 40 feet thick, whereas farther northeast the Telluride is missing altogether, although it may be represented only by an erosion surface on a weathered layer. The South Telluride area therefore was near the eastern shore of a great lake (Cross and Purington, 1899, p. 1, 13) where coarse lacustrine and possibly fluviatile (Cross, Howe, and Ransome, 1905, p. 21) deposits were forming. According to Burbank (1941, pl. 1) the age of the Telluride formation is Oligocene (?).

SAN JUAN BRECCIA

The San Juan breccia is by far the thickest formation exposed in the South Telluride area, and it is the most widely exposed unit in the section. (See plate 16.) The formation is called San Juan breccia rather than San Juan tuff in this area because of the great predominance of coarse pyroclastic material over finer grained material in this area. The formation is fairly resistant to erosion, and where it crops out in the sides of canyons and basins it generally forms steep slopes or cliffs.

The lower part of this formation is made up of 150 to 300 feet of tuff; overlying this lower part is a great thickness of usually thick-bedded breccia and tuff breccia. In part of the canyon of Bear Creek one andesite flow occurs about 450 feet above the base of the San Juan breccia. The thickness of the whole formation increases rather gradually from about 1,250 feet in the southwestern and southern parts of the area to 2,100 feet in its northeastern corner.

The tuff in the lower part of the formation is well-bedded and generally fine-grained. At the base, close to the top of the Telluride formation, there are a few coarse grains of quartz and feldspar in the tuff in places. At the top, the tuff grades rather abruptly into the overlying breccias. Except where hydrothermally altered, it has a dark-reddish or purplish-gray color. It represents the earliest volcanic debris deposited in the large lake in which the Telluride formation was formed (Cross and Purington, 1899, p. 5). The rest of the San Juan breccia, on the other hand, shows no indication of having been deposited in standing water.

The main part of the San Juan breccia consists mostly of fi coarse breccia and tuff breccia beds ranging from a few feet to abo feet thick. Interlayered are scattered, discontinuous lenses of tuff a few inches to about 10 feet thick. The blocks in the breccia: generally a mixture of as many as eight different types of vol rock, mostly andesitic or latitic in composition, and differing from other slightly in texture, grain size, amount of phenocrysts, color, presence or absence of flow structure. Little vitric or devitrified terial has been seen. Phenocrysts are common. Most of the block: subangular to rounded. The tuff breccias contain scattered l blocks, in places as much as 10 feet in diameter in a matrix of fine to lapilli tuff. The bedding planes, in many places rather indist except where tuff lenses are present, are generally rather plane faces, though local channels cut by intraformational erosion may present. Most of the formation is dark gray, usually with redd purplish, or greenish tints.

The author believes that most of the pyroclastic material in the S Juan breccia came into this area as mudflows, perhaps locally rework and sorted by running water. The lenses of bedded tuff presuma accumulated in local ponds, but most of the beds, and especially t tuff breccia beds, show no grading of size or crossbedding, as wou be expected were they deposited by running water. Conversely, the are no wedges of angular breccia such as would be deposited on t slopes of a volcano by explosive eruptions or nuées ardentes. The are no bombs with glassy edges or similar evidence of direct depositi of material by eruption.

One dark greenish-gray andesite flow, 10 to 20 feet thick, lies abo 450 feet above the base of the San Juan breccia in the middle part the canyon of Bear Creek. A thin breccia consisting solely of sma fragments similar to the andesite flow rock, is at the same stratigraph horizon farther north. The andesite flow is the only key unit in th thick formation that can be used to measure the displacement on fault Otherwise, displacements can be measured only in the overlying c underlying formations.

Fine-grained "dikes" of tuff from half a foot to about 2 feet wide ar found at a few places in the San Juan breccia. These cut massive brec cia beds that overlie lenses of tuff. Apparently the coarse bed came t rest as a unit over fine ash that was still wet and plastic; the coars material, probably drying faster than the underlying ash, cracked and was then "intruded" by the wet ash under the load of the overlying breccia.

The San Juan breccia is the oldest volcanic formation in the South Telluride area and at least the lower part of the formation is probably approximately the same age (Miocene?) everywhere in the whole San Juan region.

SILVERTON VOLCANIC SERIES

The Silverton volcanic series was originally defined (Cross, Howe, and Ransome, 1905) as covering the section "* * * between the San Juan andesitic tuffs and the Potosi rhyolite series * * *," and included from the base up, "the Picayune andesite * * *, * * * the Eureka rhyolite * * *, * * * the Burns latite complex * * *, and * * * the pyroxene andesite flows and tuffs." Later Picayune andesite was changed to Picayune volcanic group by Cross and Larsen (1935), and the Henson tuff was added at the top of the section. Burbank (1941) grouped andesite (the Picayune as originally(?) defined) with rhyolite (the Eureka), latite, and pyroclastic rocks (the lower part of the Burns) as the Picayune volcanic group, which, with the Burns latite flows and the pyroxene andesite, he put in the Silverton volcanic series. Kelley (1946) shows the Silverton volcanic series as consisting of the Picayune volcanic group (subdivided into smaller units), the Eureka rhyolite, the Burns latite (also subdivided into smaller units), the pyroxene andesite, and the Henson tuff.

A somewhat different grouping of the formations in the Silverton volcanic series has been made in this report, as the South Telluride area is on the west flank of the San Juan volcanic pile, entirely outside of the Silverton caldera, and as the rocks of the Silverton volcanic series are in large part pyroclastic types, and the flows are almost entirely typical Eureka rhyolite and Burns latite.

EUREKA RHYOLITE

The Eureka rhyolite of this area consists of two, and in places three, distinct units. The base locally consists of flows and breccia of dark andesite. Overlying this unit, or forming the base of the formation where the andesite is absent, is a group of very distinctive flows and flow breccias that appear to be similar to the typical Eureka rhyolite. The uppermost unit consists of a group of breccia beds 250 to 450 feet thick that are separated from the overlying breccias or flows of the Burns latite by a disconformity having considerable relief.

The lowest member of the Eureka rhyolite is in a relatively narrow eastward-trending strip from Gold Hill, to the east side of La Junta Basin; eastward the strip widens, occupying the middle part of the west side of the canyon of Bridal Veil Creek and all the east side of the canyon from the Little Dorrit mine to the northeast corner of the mapped area. Recent erosion limits the unit to the north of this strip west of La Junta Basin. To the north between La Junta Basin and Bridal Veil Creek, and in the south part of the map area, this unit either was not deposited or was moved by erosion before the flows of the middle member of formation were laid down. About 1,000 to 2,000 feet west of Little Dorrit mine a "fossil" hill of San Juan breccia is partly s rounded, but not covered by either the lowest or the middle memb of the Eureka rhyolite.

This lowest member of the Eureka rhyolite consists of one more very dark gray andesite flows overlain by a little breccia ma up of fragments of the same rock type. The andesite is typica rather vesicular, and the vesicles are in most places filled with ch cedony, green chlorite, and calcite. The bearing of the elongati of the vesicles strongly suggests that the flows came from an ea northeastward direction. The unit is about 30 feet thick, and pro ably thickens to the east.

This andesite unit could be correlative with part of the Picayu andesite (Cross, Howe, and Ransome, 1905, p. 7), whose type sectic lies southeast of the Silverton caldera. The author has not see this section, however, and it has seemed expedient to include th andesite with the overyling Eureka flows.

Several distinctive flows overlie the lower andesite unit where it i present and form the base of the Eureka rhyolite elsewhere. Thes flows are somewhat more resistant to weathering than the underlyin and overlying rocks and so form cliffs more commonly. They ap parently are everywhere except one locality about 2,000 feet north east of the Suffolk mine, and another locality about 1,000 to 2,00 feet west of the Little Dorrit mine.

The surface on which these flows came to rest was in general fairly level, but in places it had shallow valleys as much as several hundred feet wide. In a few places in the central and eastern parts of the area, steep-walled canyons had been cut down through the underlying andesite flow and these were filled with the flows of the second unit. Apparently the compaction of the flows, which was produced by the flattening of vesicles, was greatest over these canyons, as the top surface of the canyon-filling flows was almost everwhere occupied by a valley, now filled with the breccia of the overlying member.

This middle unit of the Eureka rhyolite is as little as 6 feet thick in places around Palmyra Basin, because erosion removed some of it before the overlying breccias were deposited. Elsewhere, it is generally between 50 and 100 feet thick, and it becomes relatively thicker toward the east; in places as much as 200 feet of flow fills canyons cut into the underlying unit.

This unit of the Eureka rhyolite has conspicuous flow structure, contains many small inclusions, and is especially characterized by numerous flattened vesicles from a fraction of an inch to 3 or 4 inches in diameter, and from a knife edge to about a quarter of an inch thick. The vesicles generally are filled with a reddish or greenish-gray extremely fine grained clayey material. Small phenocrysts of feldspar, 1 to 3 millimeters long, are scattered in a felsitic groundmass. Mafic phenocrysts (augite or biotite) are relatively rare. In the southwestern part of the area the flows are a brick red to reddish gray, but eastward they become grayer, and at the eastern edge of the area are a mixture of greenish-gray and reddish-gray rocks. Some thin flow breccias and breccias of similar rock lie between flows of this unit.

A microscopic examination of thin sections of this flow unit of the Eureka rhyolite shows that the matrix is a thinly flow banded glass, generally devitrified. Most of the phenocrysts are laboradorite but a few may be andesine. Augite and lesser amounts of biotite (mostly somewhat altered), opaque minerals, and a few small crystals, possibly orthoclase, are present. No quartz phenocrysts were seen. No matter what the composition of the matrix, the phenocrysts scarcely suggest that the rock is a rhyolite. It is not worthwhile trying to classify this rock accurately without considerably more microscopic work and chemical analysis, but probably the rock is not more silicic than a latite. Correlation with the type Eureka rhyolite is based on its position in the section and on the fact that the rock is similar megascopically (that is, as to color, texture, and the presence of many flattened vesicles) to a rock identified to the author by W. S. Burbank, as typical Eureka, north of Animas Forks and near the type section of the Eureka rhyolite.

A group of breccia beds, shown as the breccia member of the Eureka on the map, comprises the uppermost unit of the Eureka rhyolite. Except near the base, where the breccia contains a few boulders of the underlying flow rocks, breccias of the Eureka are quite similar to the breccias of the San Juan, and the two units could not be differentiated where the intervening flows do not crop out or are not present. The breccia member of the Eureka may be reworked San Juan breccia for the most part (Burbank, 1933, p. 140, 143, 144; Kelley, 1946, p. 298).

The breccia member of the Eureka rhyolite is thicker on the west side of the South Telluride area than on the east side, in contrast with the underlying flows. Thus the combined thickness of the two or three units of the Eureka rhyolite is fairly constant; the whole formation is about 500 feet thick in the neighborhood of peak 13470 on Silver Mountain, about 400 feet thick around La Junta Basin, and 460 feet thick in the northeast part of the mapped area.

The Eureka rhyolite is quite different in the area on the west si of Lookout Peak. Here only the flows with the flattened vesicles (t second member) are present. These flows are between 50 to 90 fe thick and are overlain directly by massive flows of the Burns lati Because of the poor exposures west of Chapman Gulch, it is not knov how or exactly where the change in the section comes.

BURNS LATITE

The Burns latite overlies the Eureka rhyolite, and is separated fro it by a disconformity having considerable relief, so that in differe places different parts of the Burns latite are in contact with the unde lying breccias or flows of the Eureka. This disconformity must rep resent a considerable time interval, as the pre-Burns erosion surfac was formed on well-lithified breccia.

The most complete section of the Burns latite consists of the follow ing parts, omitting consideration, for the present, of the local basi andesite at the top:

(*a*) As much as 20 feet of volcanic conglomerate containing, especially nea the base, many well-rounded (presumably water-worn) and heavily iron-stained boulders that were deposited only in the lower parts of channels on the underlying erosion surface. This grades upwards into *b*.

(*b*) A breccia, with some tuffaceous layers, as much as 100 feet thick. Both this member and the underlying volcanic conglomerate contain some fragments similar to the overlying flows of the Burns latite; these fragments are the means of differentiating this breccia from the underlying breccia of the Eureka rhyolite in places where the disconformity cannot be seen. Overlying this is *c*.

(*c*) From 75 to 100 feet of thin fissile andesitic or latitic flows, containing abundant feldspar phenocrysts, and having some flattened vesicles filled with green chlorite. At the top is *d*.

(*d*) Thicker and more massive flows of approximately the same composition as the thinner, underlying flows. This unit is the most resistant to erosion, and generally forms cliffs where present in the section.

All the flow rocks (*c* and *d*) are dark greenish gray and reddish gray. They contain considerable hornblende and biotite in addition to the abundant feldspar phenocrysts, and apparently have the composition of andesite or hornblende latite.

The Burns latite is exposed only on the higher ridges and in the upper basins in the area of the report. It crops out around the higher ridges surrounding Palmyra and Gold King Basins, east on each side of the main ridge north of Howard Fork; in the ridges around La Junta Basin, around La Junta Peak, across the middle of Bridal Veil Basin, and around the three cirques East Basin, Mud Lake Basin and Grays Basin. It is cut out in places on the north side of the valley of Howard Fork by the Spring Gulch diorite intrusion and is unrecognizable because of intense hydrothermal alteration in the area north and northeast of the Carbonero mine where it presumably makes up the upper part of the area of hydrothermally altered Silverton volcanic series and San Juan breccia. It occupies a considerable area on the west side of Lookout Peak and in Ophir Pass. The only places where it is found at lower altitudes are on the ridges on the north and south sides of Palmyra Basin, where it is down faulted in a small graben; presumably it also underlies the Potosi volcanic series farther west on the ridge on the north side of Palmyra Basin, in the Palmyra graben (pl. 17).

The Burns latite is variable in thickness in the mapped area. At the west edge of the area, fissile flows aggregating 75 to 90 feet occur on a fairly level surface cut by local channels containing as much as 10 feet of breccia and about 15 feet of volcanic conglomerate. Eastward the relief of the underlying surface increases, the breccia is almost everywhere, and the massive flows overlie the fissile flows. Except for the area around Ophir Pass, the average thickness of the formation is about 300 feet. It thins over buried hills or "steptoes", and at a place about 900 feet east of the Little Dorrit mine, the whole formation is missing, as it wedges out against a buried hill of breccia of the Eureka rhyolite. At other places in the eastern part of the area, the total thickness is considerably more than 300 feet in the deep "fossil" valleys.

In the Ophir Pass area and on the west side of Lookout Peak, the Burns latite changes both in character and in thickness. Here it consists almost entirely of thick flows of massive rock which are, however, still recognizable by the abundant feldspar phenocrysts. The latite appears to be about 900 feet thick, and both the underlying Eureka rhyolite and the lowest member of the overlying Potosi volcanic series are much thinner than elsewhere.

This greater thickness of massive flows, plus the fact that steeply dipping and even vertical flow lines were observed at places on the north side of Ophir Pass, suggests that this area is quite close to at least one of the extrusive centers from which the material of the flows issued.

At the south and east sides of a small subbasin around the Lewis mine, in Bridal Veil Basin, lenses of very dark flow rock, underlain and overlain by a little dark breccia, are between the typical massive flows of Burns latite and the overlying Potosi volcanic series. This flow has a maximum thickness of 40 feet, and probably is mafic andesite; the rock contains small phenocrysts of pyroxene and altered olivine (probably iddingsite or iron oxides (Larsen and others, 1936, p. 701)). Quite likely it represents the westernmost extent of the pyroxene andesite unit of the Silverton area. The flow and the accompanying breccia occurs in such small amounts in the mapped area, however, that it has been included as a member of the Burns latite.

POTOSI VOLCANIC SERIES

The youngest of the Tertiary volcanic formations in the South T luride area is the Potosi volcanic series. These rocks are genera found only on the higher ridges and peaks, and their distribution similar to but slightly more restricted than that of the Burns lati The rocks appear to have been laid down on a fairly even su face marked by only a few minor depressions or valleys. The conta with the Burns latite is a disconformity representing a considerab time interval, during which most of the pyroxene andesite, the Hens tuff, and the Sunshine Peak rhyolite were laid down farther ea (Cross and Larsen, 1935). The maximum thickness of the formatio as shown on the east side of the area, is approximately 1,100 feet. I can be subdivided into six units in the report area; in much of thi area, however, only the bottom three units are present.

The lowest unit, 300 to 350 feet thick, consists of one or two layer of pinkish-white weathering quartz latite. It is possible that thes rocks may be welded tuffs rather than flows. Although somewhat fis sile where weathered, this unit forms some of the most prominent cliffs in the area; these cliffs usually present the greatest obstacle for those who climb the high peaks in the area. The unit is a light-gray rock on fresh surfaces that contains prominent phenocrysts of potash feldspar and sodic plagioclase (the latter usually extremely altered) as well as many phenocrysts of black to light-bronze-colored biotite and many generally small (½ to 2 inch) inclusions of andesite and latite.

The next unit of the Potosi volcanic series consists of several gray quartz latite flows, 50 to 100 feet thick, which, almost everywhere, form a talus-covered ledge above the cliff formed by the underlying quartz latite. It was called the Cannonball unit during fieldwork, because in places it contains rather unusual hard concentric masses, from a few inches to several feet in diameter, which weather out from the flow; the name Cannonball, however, is preempted and so cannot be used for this unit. Each mass has a small foreign inclusion at the center, but consists for the most part of rock identical with the rest of the flow except that it is slightly harder. Where these "cannonballs" are not present, the quartz latite has thin black flow streaks. In places the rock has spherulitic structure or may contain large blocks of reddish-gray quartz latite that appear to be pieces of the top crust that rolled down into the lava. Except for some phenocrysts of potash feldspar and altered plagioclase, this unit consists almost entirely of devitrified glass.

On top of the gray quartz latite is another cliff-forming unit consisting of one or more layers of glassy banded rhyolite, aggregating 250 to 300 feet in thickness. This unit weathers to a dirty white or light gray, but in many places is rather heavily iron-stained to a reddish or brownish gray by the oxidation of disseminated pyrite, which was deposited during the hydrothermal alteration that affected much of the Potosi volcanic series. The glassy-appearing bands, one-eighth to one-quarter inch wide, alternate with more felsitic bands. This unit is highly siliceous; potash feldspar phenocrysts are present in a completely devitrified glass, now made up apparently of fine-grained quartz and orthoclase which may contain relict flow-banded structures.

A red to purplish-gray member, 75 to 100 feet thick, overlies this rhyolite member; it is relatively nonresistant to weathering and is generally poorly exposed, forming a talus-covered ledge between the rhyolite cliffs. It consists of some flows with spheroidal structures and some tuff and breccia, all probably close to quartz latite in composition.

The second cliff-forming rhyolite member, 200 to 300 feet thick, is similar to the lower one except that the glassy banding is less evident.

The top of the Potosi volcanic series in this area is a dark-gray andesite flow about 40 feet thick that appears only as a capping at Lookout Peak.

For the members of the Potosi volcanic series, thicknesses are given only in round numbers and with a large possible range because the members are usually in steep cliffs around the higher peaks and ridges, the less resistant members are heavily covered with talus, and the actual contacts are rarely seen.

TERTIARY VOLCANIC HISTORY

A provisional Tertiary volcanic history for the flank of the San Juan volcanic pile as exposed in the South Telluride area is as follows:

After the deposition of the Telluride formation in Oligocene(?) time, volcanoes erupted somewhat to the east, and relatively fine-grained tuff was washed into the lake in which the Telluride formation had been deposited. The tuff was covered by a thick unit of coarse pyroclastic material, which the author believes was derived from several different volcanoes to the east and came into this area mostly as volcanic mudflows (Anderson, 1933). At one time an andesite flow reached this area from one of the volcanoes and was buried by more breccia. At times running water reworked the material, and lenses of tuff were formed in local ponds on the surface of the mudflows. All this material makes up the San Juan breccia. At the end of San Juan time, one or more flows from a distant volcano, whence the andesite of the Picayune volcanic group poured out, reached part of this area, probably after erosion had cut some relief on the San Juan breccias.

Vigorous erosion followed deposition of the San Juan and Pic formations, and some steep-walled canyons were formed. T east, one or more volcanoes began erupting the lava of the Eı and some flows reached this area. Probably the Silverton ca started subsiding at this time, and as its floor sank, about 2,00 of flows were accumulated in it, whereas only about 200 feet of si rock were deposited in this flank area. These flows are overla several hundred feet of breccia, probably laid down soon afterw A considerable length of time then elapsed, during which the bre of the Eureka were lithified, and erosion cut an irregular su with a relief of several hundred feet.

Then, somewhere to the east, volcanoes began erupting the f of the Burns latite. At first only water-transported material rea the mapped area, and was deposited in valleys as volcanic congl erate. Coarser, more angular material, perhaps carried mainly volcanic mudflows, covered the conglomerate. Then the fissile fl of the Burns, followed by the more massive flows, came into this a burying all the surface of the country except the higher hills, wh protruded through the younger flows as partly buried hills, or stept During this time the Silverton caldera to the east continued to si and the Burns latite accumulated in greater thickness in it. It suspected that at least one of the centers of eruption for these la was near what is now called Ophir Pass.

The Silverton caldera continued to sink, and a great thickness pyroxene andesite formed within it. Only when the caldera w filled, perhaps, did one thin flow of this mafic andesite reach out far on the flank as Bridal Veil Basin.

Then followed a long period of erosion during which the mapp area, as well as probably the whole San Juan region, was reduce to a great plain on which there were only a few shallow valleys. Th whole region was then covered by the Potosi volcanic series. In th South Telluride area, this formation consists of three relatively silici (quartz latite or rhyolite) members in thick, evenly distributed units alternating with thinner units of more mafic composition (quart latite or andesite). As silicic lavas are generally rather viscous an tend to form flows that are lenticular in cross section, the wid distribution in this region of silicic volcanic rocks of fairly uniform thickness suggests that all these rocks may be welded tuff.

This is the end of the volcanic history in the South Telluride area. To the east more volcanic formations were laid down (Cross and Larsen, 1935), and then the whole area was subjected to a long and complicated history of erosion as described by Atwood and Mather (1932).

TERTIARY INTRUSIVE ROCKS

Intrusive rocks are rare in the north half of the mapped area, but become increasingly abundant to the south. Three larger intrusive masses, as well as some smaller plugs and many dikes, are on the north side of the valley of Howard Fork. Several dikes crop out along the west side of the mountains as far north as Gold Hill, around Lena Basin, and on the south side of East Fork Basin. A few are present farther down Bear Creek, in La Junta Basin, and in upper Bridal Veil Basin. One occurs in the south end of East Basin, and another extends from the lower part of the creek draining Blue Lake, across Bridal Veil Creek, the lower parts of Jackass and Silver Lake Basins, to the edge of the canyon of the San Miguel River southeast of Telluride. A few small pluglike intrusions crop out in the ridges southwest of the Gold King Basin and in the southeast corner of East Fork Basin.

Cross and Purington (1899) referred to two large areas of "granite porphyry" east of Ophir as "a porphyry body, cut in two by Howard Fork, which is in some respects analogous to a laccolith, although somewhat irregular in its relations to the inclosing sedimentaries." The southern body, off the south edge of the present map, may be as shown by Cross and Purington (1899); at a few points along Howard Fork coarse-grained quartz-feldspar porphyry was seen and was called quartz monzonite porphyry during fieldwork. The body shown on the north side of the valley, however, if present at all, is much smaller than as shown by Cross and Purington (1899), and is a different rock type than that south of the Howard Fork. Some of the scattered outcrops of quartz-feldspar porphyry on the map may be part of a single, very irregular body extending from a little west of the gulch on which the Carbonero mine is located eastward to the outcrop where the Hattie mine is located in Chapman Gulch. The author believes, however, that these exposures of quartz-feldspar porphyry are parts of several pluglike intrusions similar to the one just east of Spring Gulch and the one on the main ridge east and northeast of the Highline mine, but outcrops are too poor to prove the relations.

Several similar, somewhat smaller, quartz-feldspar porphyry bodies occur east and west of Chapman Gulch, and three small ones lie in the southeast corner of East Fork Basin. Although there is some variation in the composition of the different plugs, it is believed that they all approach an acid quartz monzonite in composition. Most of them are greatly altered.

The two largest masses of intrusive rock in the valley of Howard Fork are mainly dioritic in composition. The Ophir Needles body, extending from near Ophir Loop, north and east to within about a thousand feet of the Badger tunnel, is part of a larger mass that tends south of the Howard Fork and west of the Lake Fork of the Miguel River (Cross and Purington, 1899). This rock is descril and a chemical analysis of it is given by Cross and Purington (18 p. 6). According to them the diorite mass has a number of variati that show transitional contacts. Although a detailed study was made of the Ophir Needles mass, sharp contacts were seen between finer grained diorite and somewhat coarser grained monzonite. T diorite contains mainly labradorite, augite, and a little hypersthe The monzonite, however, contains considerable orthoclase with t laboradorite or andesine, and somewhat less augite, some biotite, and hypersthene. In some places the monzonite is fairly even graine with the grains averaging about 1 mm in length; in some places it has seriate texture with the larger grains close to 5 mm long; in oth places it is porphyritic, having phenocrysts 1 to 6 mm long and ground mass crystals averaging half a millimeter in length. The color of bot the diorite and the monzonite ranges from dark to light gray, th coarser-grained types being lighter in color.

Several small bodies of diorite crop out in Ophir Pass. Possibly the are small protrusions above a considerably larger intrusion underlyin Ophir Pass and the area to the north. The presence of such an intru sion is suggested because all the rocks between Ophir Pass and the east ward-trending fault, about 1,400 feet south of Lookout Peak, contair considerable epidote, which is a common contact metamorphic minera in this region.

Three small plugs are exposed north of the Ophir Needles intrusion, in the ridge southwest of the Gold King Basin, and on the south side of the next small cirque southwest of this basin. The more irregular-shaped body that crops out on the ridge southwest of the Gold King Basin is monzonite, containing considerable orthoclase in the groundmass and phenocrysts of labradorite and augite. This body connects with a small circular body about 400 feet to the east by a dikelike extension. Farther up the ridge, to the south, a small elliptical body of diorite cuts the monzonite; it consists mostly of labradorite and augite and a little hypersthene. The third body of this group is composed of monzonite and crops out on the southwestern side of the small basin southwest of the ridge. Judging from the metamorphism of the San Juan breccia surrounding this basin, the intrusion may underlie a good deal of the talus-filled basin. These three bodies lie within an area that is bounded in part by a circular fault and may thus be the upper part of a larger, compound, pipelike intrusion, similar perhaps to some of those described by Burbank (1941, p. 170–178, 246, 247).

There are many dikes in the South Telluride area, and they are especially numerous between the Ophir Needles diorite body and the Gold King Basin. Although they were called basic dikes in the field, they are mostly pyroxene andesite and latite. They range in width from less than 3 feet to about 40 feet, averaging about 10 feet. Some are fairly continuous for more than 2 miles, others appear only discontinuously along a single fracture, and still others are arranged in a distinctly en echelon pattern. There are many exceptions, but in general the northwestward-striking dikes are the oldest, followed in turn by the sparse westward-trending dikes and by the northward-trending dikes; the northeastward-trending dikes are the youngest. Most of the dikes appear to be older than the larger stocklike or pluglike intrusions, but a few do cut these intrusive bodies.

Many of the dikes are porphyritic and contain phenocrysts of labradorite, augite, or both. The pyroxene andesite dike rocks consist of labradorite with lesser and variable amounts of augite. The latite dike rocks usually contain phenocrysts of labradorite or pyroxene, but the groundmass contains a considerable amount of potash feldspar along with either andesine or labradorite, and may also contain a little biotite, hornblende, and quartz. Most of the dikes are greenish gray on fresh surfaces, and the pyroxene andesite is darker than the latite. Alteration usually lightens the color. Some dikes have lines of vesicles parallel with the edges; generally before weathering the vesicles contained calcite. As seen in thin section most of the dikes are flow banded with the feldspar laths arranged subparallel.

The dike rocks are commonly altered so thoroughly that only a guess can be made as to the original constituents. Sericite replaces the feldspars, chlorite replaces the mafic minerals and, in places, the plagioclase. Calcite is common throughout some of the dikes. Most of the quartz is probably secondary and formed during alteration. Some of the alteration may have been deuteric, but most of it is believed to have been hydrothermal. The dikes and adjacent rocks were strongly altered because of their location in and near fractures that were the principal channelways for solutions. A few dikes have frozen contacts and appear to be somewhat less altered. Like the altered country rock, the more intensely hydrothermally altered parts of the dikes weather brown from the oxidation of the pyrite, which was generally deposited during alteration.

In the area between the Ophir Needles diorite body and Gold King Basin, the oldest dike, an irregular intrusion of latite as much as 75 feet wide that strikes northwestward, now is considerably altered and contains much epidote and clinozoisite. Approximately six other dikes strike northwest, seven strike north, two about west, and five strike northeast. In general each dike differs a little from all others in color, grain size, character of phenocrysts, or in presence amount of vesicles.

In the ridges from Gold King Basin to Gold Hill most of the strike northwest or northeast. The northwestward striking dike the older, with the exception of the large dike along the north ward striking Alta vein zone, which appears to be younger the northeast dikes. A study of plate 16 shows other dikes in Basin, East Fork Basin, in Bear Creek canyon as far north as Champion mine, and in La Junta Basin. A thick (15 to 25 f dike with a distinctive porphyritic texture (phenocrysts of plagio as much as one-half an inch long) extends from a point nort Green Cone, across Bear Creek and into La Junta Basin. In La Ju Basin it twice occupies northward-striking fractures, then contin eastward under a large area covered by talus.

At the south end of Bridal Veil Basin, thin dikes, arranged echelon along the south shore of Lewis Lake, extend northeastw from the lake. Another thin dike about 5 feet wide strikes east acr Bridal Veil Creek a little way south of the Little Dorrit mine; it extremely altered and so bleached in places that it resembles rhyoli To the west it curves southwestward and apparently dies out after o en echelon-type offset. To the east, it is exposed in places along fracture zone that crosses the south end of East Basin. The only oth dike of any size in the eastern part of the area occurs discontinuous along the Millionaire fracture zone (pl. 17); after a change of stri this dike and the fracture zone continue north of the San Miguel Riv as the Alleghany vein. (See map, Burbank, 1941.)

Only a few breccia pipes of the type so common in the Red Moun tain district (Burbank, 1941, p. 170–178) farther east, are exposed i the South Telluride area. All are on the north side of the east end o the valley of Howard Fork in the area of intensely altered rocks where outcrops are few and poor. Because of the few exposures it i quite likely that more such pipes are present than were found; thes pipes may be associated with the numerous small pipelike intrusion of quartz-feldspar porphyry. The breccia pipe along the next gulch east of the Carbonero mine is too poorly exposed to show whether it is associated with a porphyry pipe; the breccia is highly sericitized and has much disseminated pyrite in it.

The breccia pipe in Chapman Gulch, about a thousand feet northeast of the Calumet mine, apparently is quite similar to those described by Burbank (1941, p. 170–178). It has an oval-shaped outcrop of breccia about 500 feet in greatest dimension, whose center and eastern part is filled with quartz-feldspar porphyry. The generally angular or platy fragments of the breccia, ranging in size from less than a quarter of an inch up to about a foot and averaging about 3 inches, are replaced by much quartz and coarse-grained sericite, both also filling the interstices between the fragments. The weathered and leached rock is light yellowish-gray, with only a little brown stain from oxidized pyrite. The porphyry mass within the pipe is strongly altered and contains considerable disseminated coarse pyrite.

The third pipe seen in this area occurs rather low in the next gulch west of Chapman Gulch. Probably it represents a further stage in the silicification and sericitization processes seen in the Chapman Gulch pipe, as it consists almost solely of quartz and sericite, which are accomplished by pyrite and a little molybdenite.

Only two small "pebble" dikes were seen in the South Telluride area. Both were on the west side of Bridal Veil Creek, one west of the Royal mine, the other east of La Junta Peak. They occupy northward-trending fractures and are from 6 inches to 3 feet wide. They consist of 1- to 2-inch fragments of sandstone and shale, from pre-Tertiary formations (probably in part the Dolores formation) in a sandy matrix containing some clay material.

METAMORPHISM AROUND TERTIARY INTRUSIVE BODIES

The intrusion of the bodies of diorite and monzonite was accompanied by considerable contact metamorphism of the country rock. Metamorphosed pre-Tertiary rocks are especially well exposed on the west side of the Ophir Needles, northeast of Ophir Loop. Here the Brushy Basin member of the Morrison formation consists of alternating beds containing different proportions of biotite, epidote, other calc-silicate minerals, quartz, and magnetite. The rocks are hard, generally fine-grained hornfels, and range in color between dark green and various shades of gray. The main visible effect of the metamorphism has been, therefore, the reduction of the iron oxide, and the formation of calc-silicate minerals and biotite.

The lower sandstone of the Dakota sandstone was altered to a sandy quartzite with little color change. The upper part of this formation and the Mancos shale were changed to a succession of beds of quartzite and dark- to light-colored fine-grained hornfels, some containing calc-silicate minerals.

The Telluride formation was little changed by metamorphism, beyond a slight hardening and a change in color from reddish to gray.

The overlying tuff and breccia beds of the San Juan breccia were greatly changed; both the tuff and the breccia were recrystallized to such an extent that within 300 to 400 feet of the contact it is very difficult to distinguish them from the intrusive rock, especially on fresh